

APS Plasma Propulsion Mini-Conference Abstract
November 18, 2004, Savannah, Georgia

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Title: Computational Modeling of NEXT 2000-hour Wear Test Results

Ion optics computational models are invaluable tools for the design of ion optics systems. In this study, a new computational model developed by an outside vendor for NASA Glenn Research Center (GRC) is presented. This model is a gun code which has been modified to model the plasma sheaths both upstream and downstream of the ion optics. The model handles multiple species (e.g. singly and doubly-charged ions) and includes a charge-exchange model for erosion estimates. The model uses commercially available solid design and meshing software, allowing high flexibility in ion optics geometric configurations. This computational model is compared to experimental results from the NASA Evolutionary Xenon Thruster (NEXT) 2000-hour wear test, including over-focusing along the edge apertures, pit-and-groove erosion due to charge exchange, and beamlet distortion at the edge of the hole pattern.

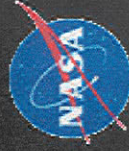
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Computational Modeling of NEXT 2000-hour Wear Test Results

Shane P. Malone

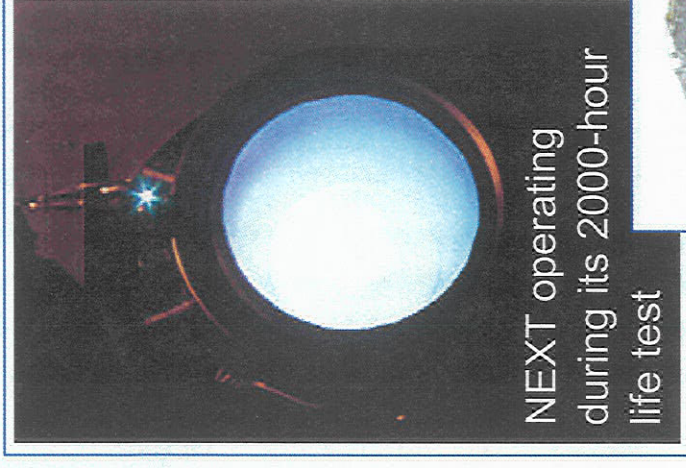
NASA Glenn Research Center
Cleveland, Ohio

Glenn Research Center at Lewis Field



NEXT Ion Thruster

- The NEXT ion thruster is a 40 cm diameter, ring cusp, two-grid electrostatic ion thruster intended for primary propulsion on interplanetary science spacecraft
- The NEXT ion thruster underwent a 2000-hour wear test intended to:
 - Identify thruster life-limiting phenomena & measure thruster component wear rates
 - Characterize the operation of the thruster over an extended duration
 - Compare measured wear rates of the thruster with that predicted from life models

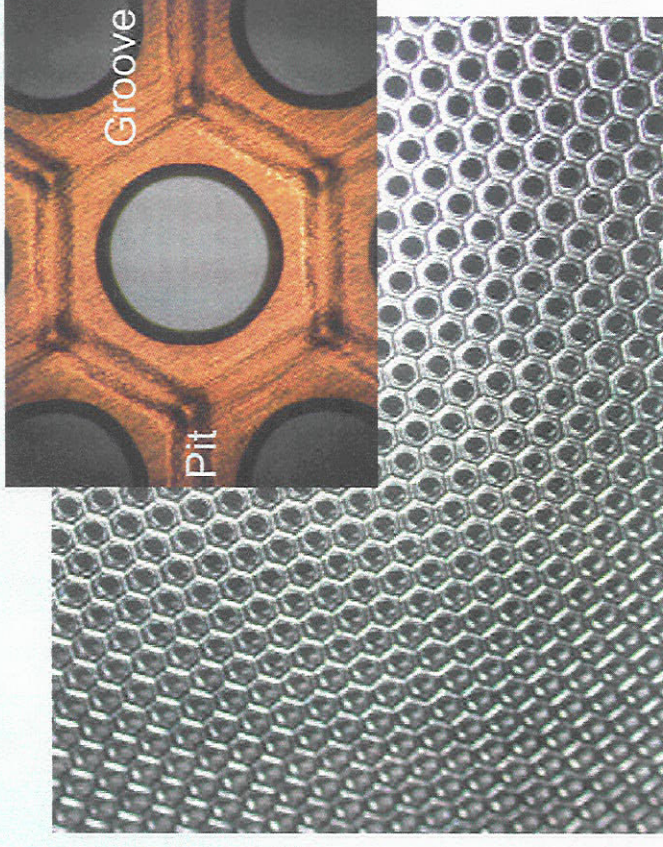


NEXT operating during its 2000-hour life test



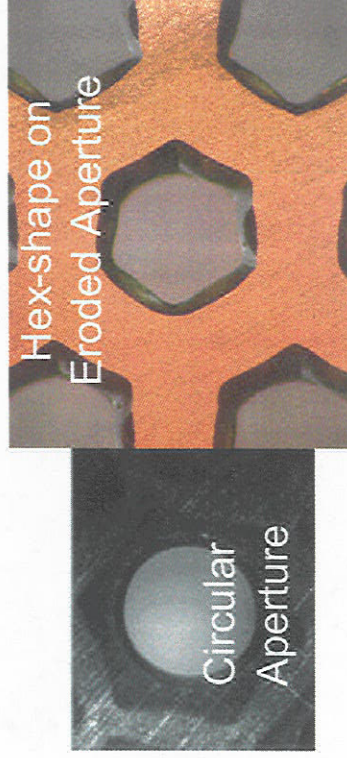
Optics Erosion Mechanisms

- Ion optics used on ion thrusters tend to sputter erode over time
- There are two primary mechanisms for this
 - **Pit-and-groove erosion** of the downstream accelerator grid face
 - Accelerator grid aperture enlargement due to **crossover erosion** of primary ions and barrel impingement of charge exchange ions



Pit-and-Groove Erosion

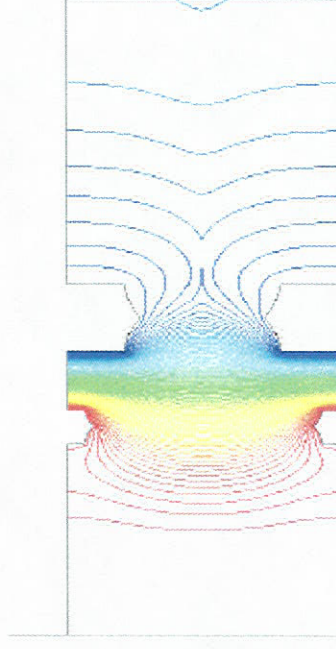
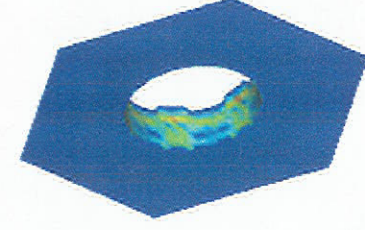
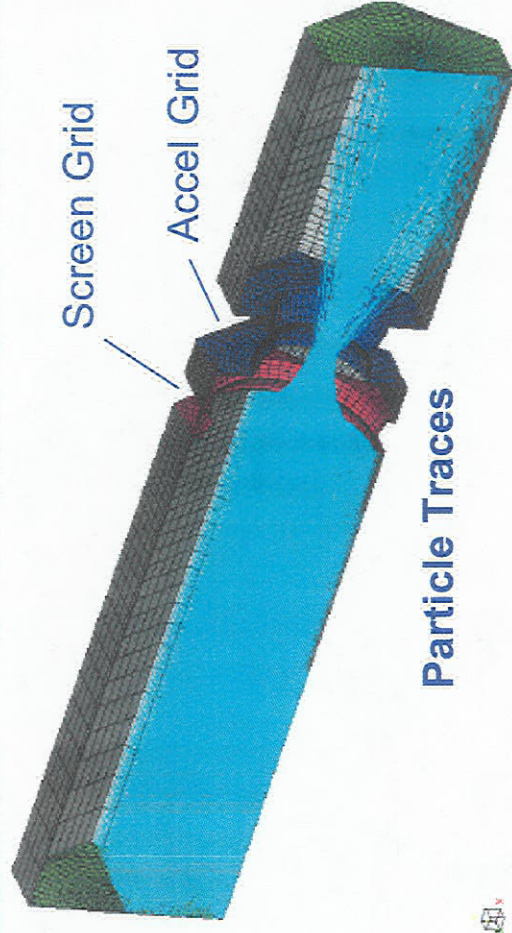
- Both of these erosion mechanisms can lead to thruster failure!



Crossover Erosion

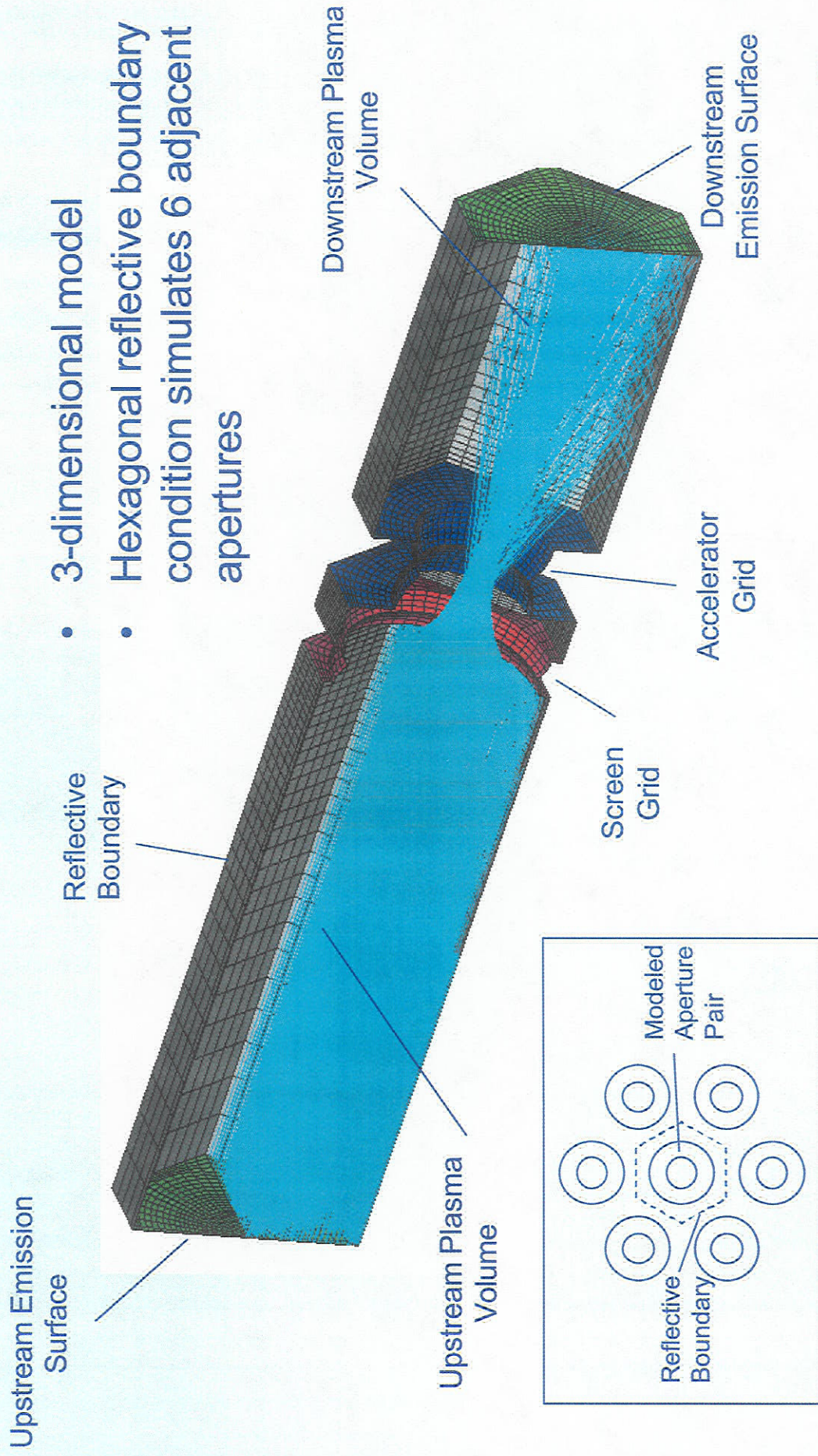
Computational Modeling

- Computational modeling can be used to predict ion optics performance and erosion over time
- The 3-dimensional code developed for the Glenn Research Center has numerous benefits
 - Professionally supported, commercially developed code
 - Commercially available solid modeling and meshing programs allow tremendous flexibility with geometry and mesh structure
 - Code supports multiple ion species and multiple generations of charge exchange



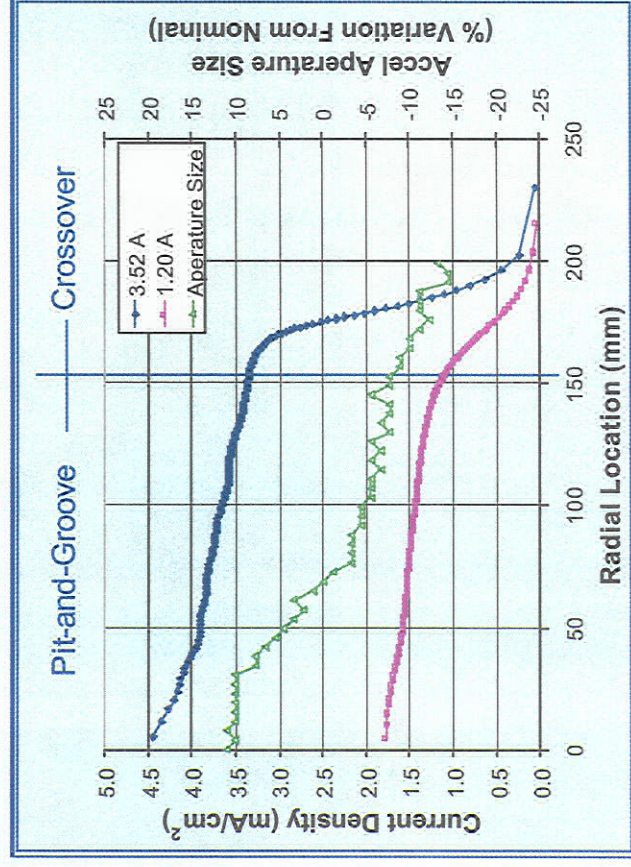
GRC Computational Modeling

- 3-dimensional model
- Hexagonal reflective boundary condition simulates 6 adjacent apertures



NEXT Model Inputs

- Screen and accelerator grid voltages match test settings
- Aperture sizes measured using pin gages
- Plasma parameters determined from diagnostics or calculated
- Neutral density calculated and assumed constant over thruster optics surface



(% Variation From Nominal)

Model Inputs

	$J_b = 1.20 \text{ A}$	$J_b = 3.52 \text{ A}$
V_a	-260 V	-220 V
V_s	1765 V	1766 V
ϕ_u	1796 V	1796 V
ϕ_d	6 V	6 V
T_{eu}	6 eV	6 eV
T_{ed}	1 eV	1 eV
n_{neut}	$1.29 \times 10^{18} \text{ m}^{-3}$	$3.27 \times 10^{18} \text{ m}^{-3}$

Upstream

$$n_{i_u} = \frac{j_{beamlet}}{e} \sqrt{\frac{m_{Xe}}{T_e}}$$

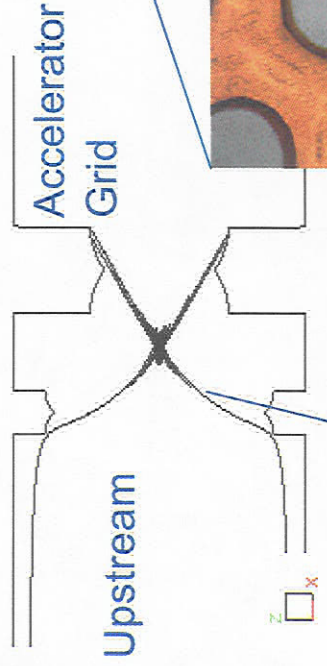
Downstream

$$n_{i_d} = \frac{j_{beamlet}}{eV_{i_d}}$$

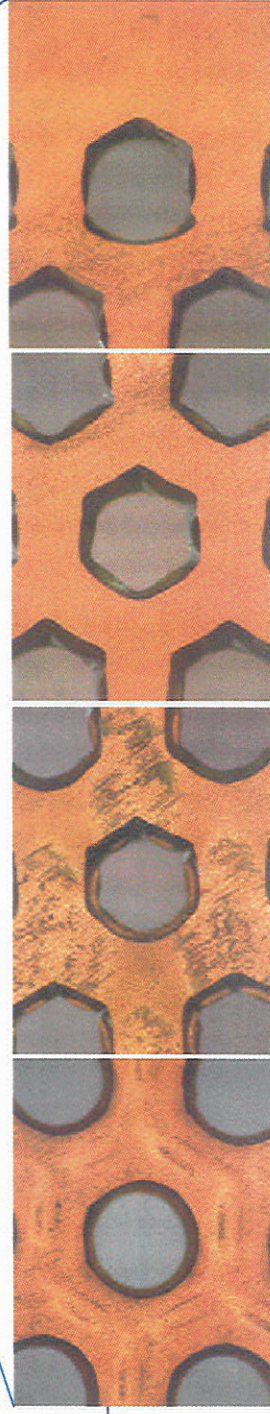
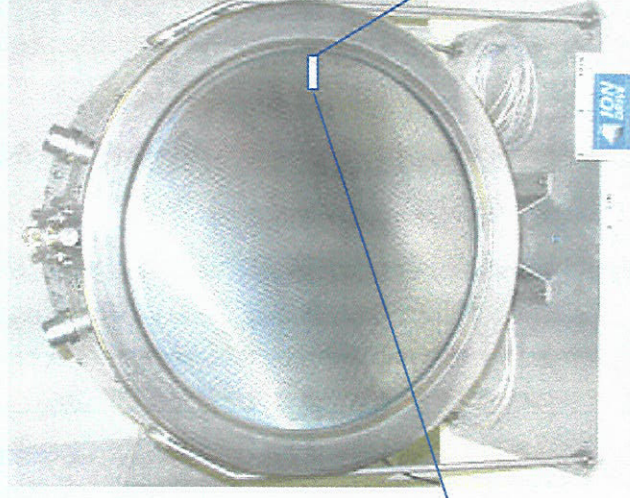
$$V_{i_d} = \sqrt{\frac{2eV_{net}}{m_{Xe}}}$$

NEXT Crossover Erosion

- Crossover erosion noticed at radii greater than 153 mm
- Possible causes of crossover erosion
 - Low plasma density at outer edge of grids
 - Smaller than normal aperture sizes at outer edge of grids
 - Misalignment of screen and accelerator grid apertures due to under-compensated hole pattern



Over focused ions cross over centerline to strike opposite aperture wall



$r = 153 \text{ mm}$

$r = 184 \text{ mm}$

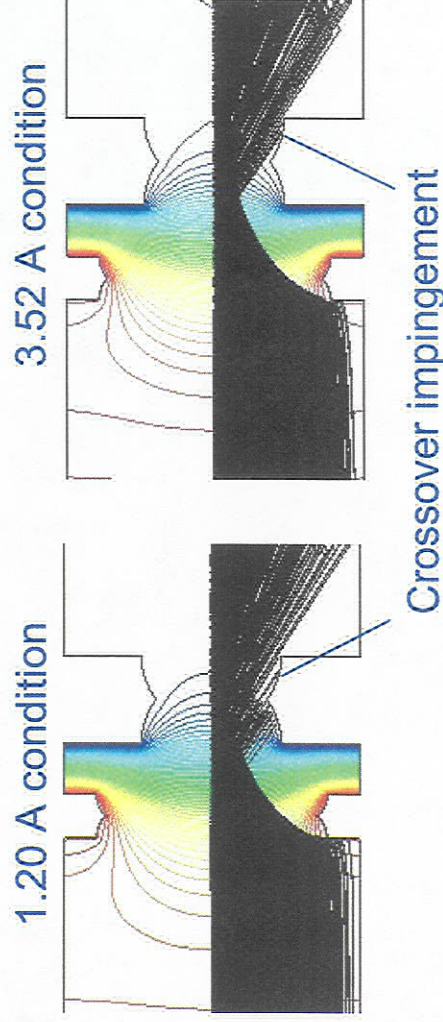
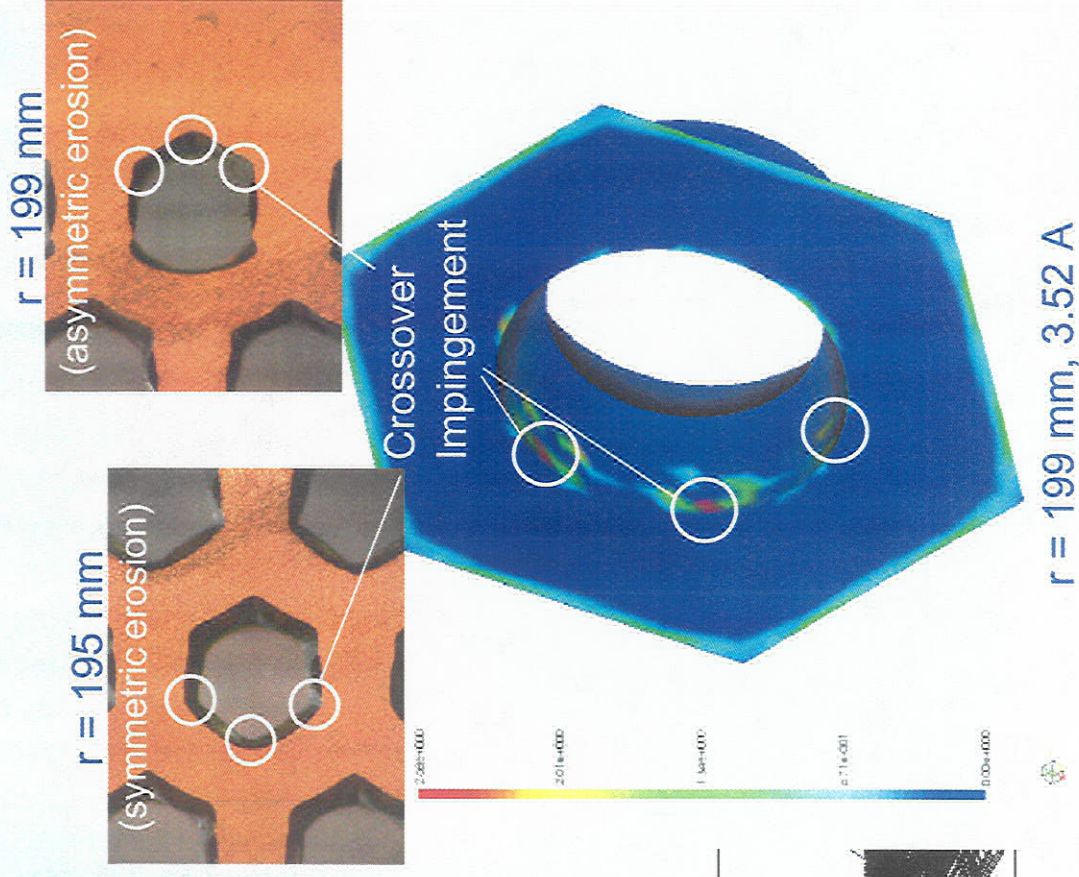
$r = 195 \text{ mm}$

$r = 199 \text{ mm}$



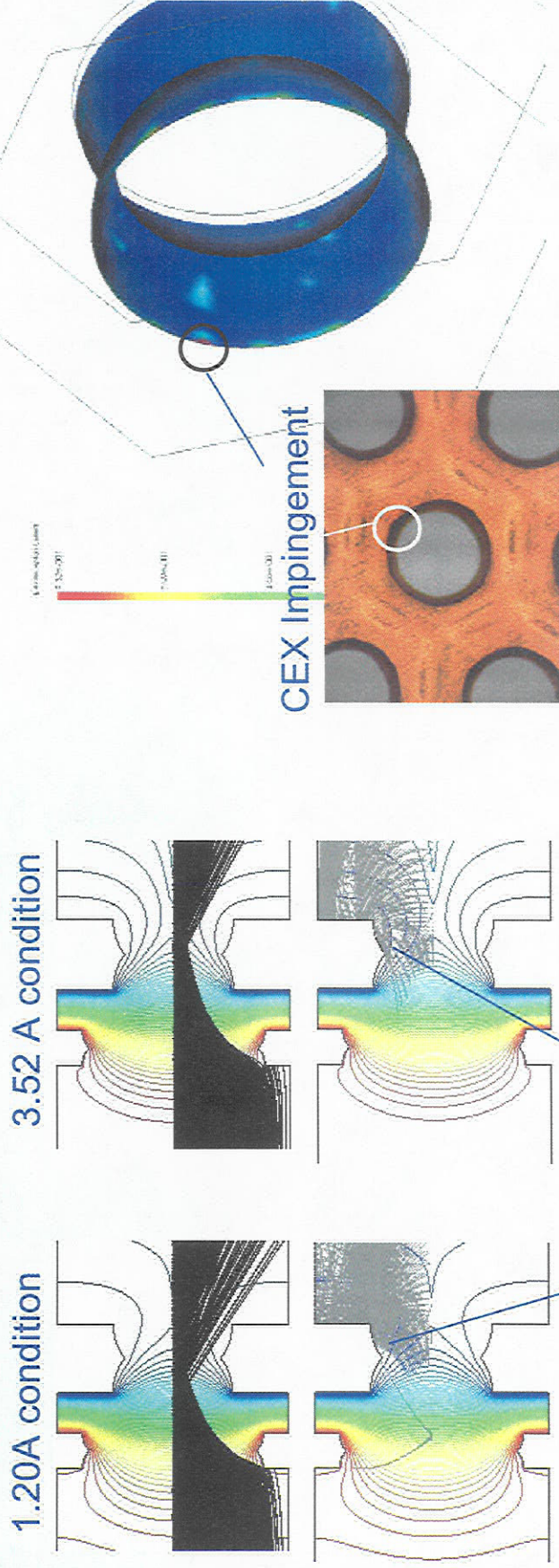
Crossover Erosion at $r = 199 \text{ mm}$

- Model clearly indicates impingement of crossover ions on accelerator grid aperture barrel
- Current deposition pattern indicates most ion impingement along hex “points”, matching pattern seen in wear test



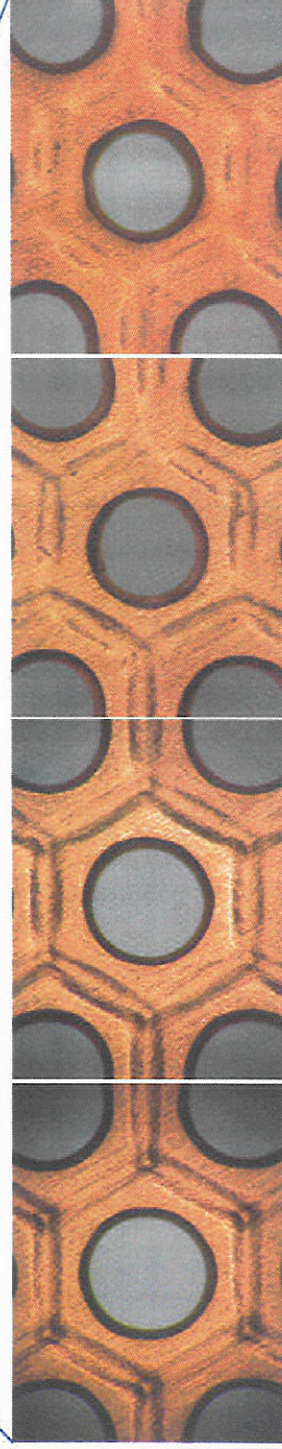
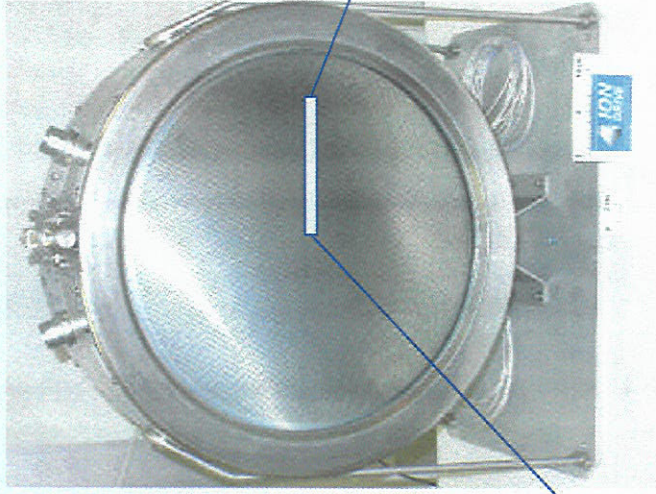
Crossover Erosion at $r = 153 \text{ mm}$

- Crossover impingement by primary beam ions **not** seen in model results
- Small impingement of medium and high energy intergrid CEX ions **may** contribute to slight erosion along webbing direction
 - Aperture enlargement effect – looks like crossover erosion due to hex shaping of barrel



NEXT Pit-and-Groove Erosion

- Pit-and-groove erosion noticed at radii less than 153 mm
- Pit erosion most nearer to thruster centerline
- Groove erosion highest near quarter radius of thruster
- Caused by charge exchange ions formed downstream of the ion optics



$r = 8 \text{ mm}$

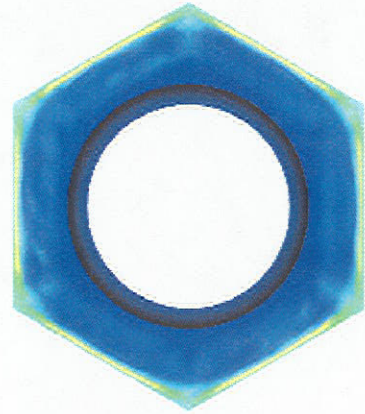
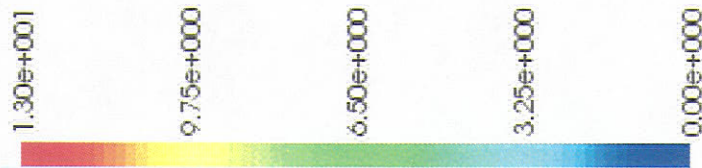
$r = 50 \text{ mm}$

$r = 100 \text{ mm}$

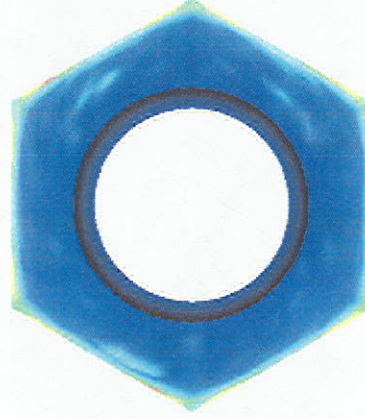
$r = 153 \text{ mm}$

Charge Exchange Pit-and-Groove Impact

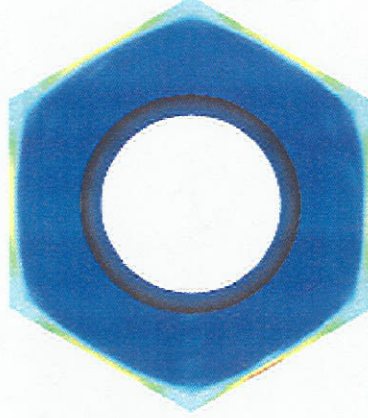
Impingement
Current Density
(A/m²)



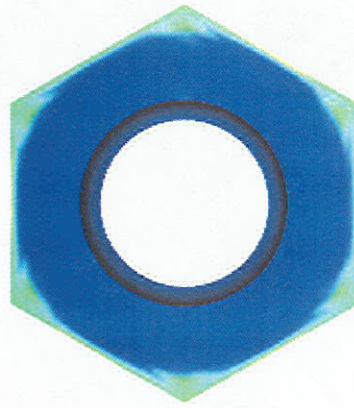
$r = 8 \text{ mm}$



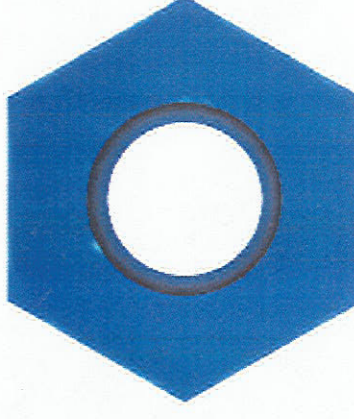
$r = 50 \text{ mm}$



$r = 100 \text{ mm}$



$r = 153 \text{ mm}$

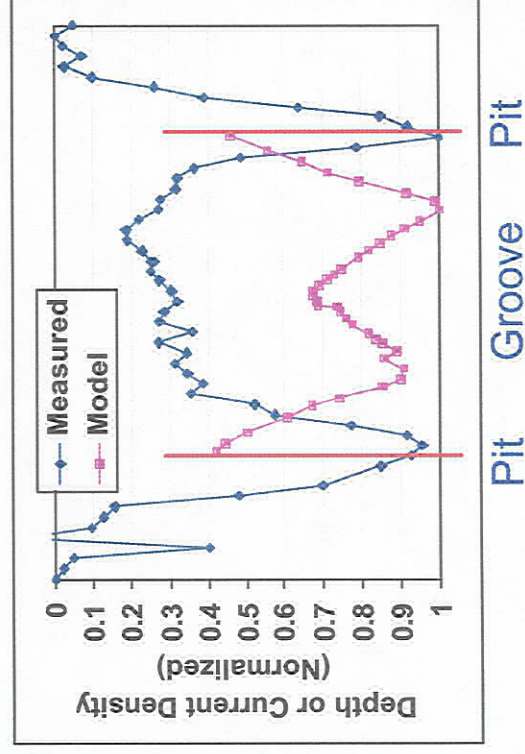
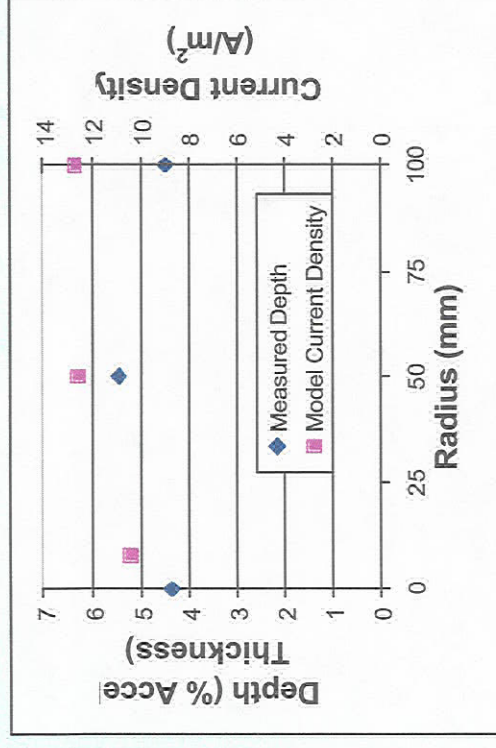
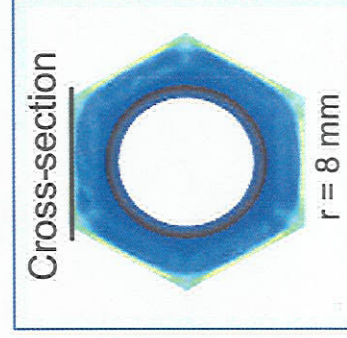
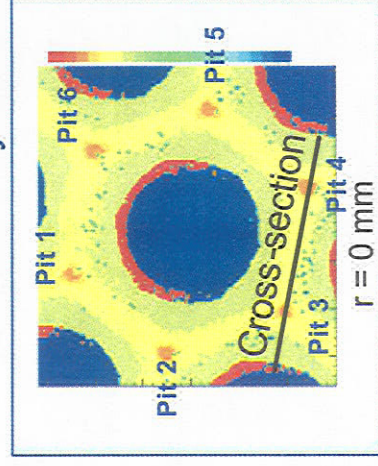


$r = 199 \text{ mm}$

Impingement of CEX
ions onto downstream
surface of accelerator
grid at different radial
locations

Analysis of Pit-and-Groove Erosion

- Model shows similar trend to measured data regarding groove depth
 - Grooves are deeper away from thruster centerline
- Model does not agree with pit and groove pattern near thruster centerline
 - Model indicates deep groove rather than pit
 - May be due to mesh geometry



Conclusions

- Ion optics computation model developed for NASA-GRC is extremely flexible in geometry
- Model accurately recreates crossover impingement seen during the NEXT 2000-hour wear test
- Model shows proper trend in groove depth but does not show proper pit-and-groove pattern seen near thruster centerline
- More work required to improve model performance

Future Work

- Modeling of edge apertures to simulate “missing” apertures at the edge of the hole pattern
- Improve simulation of pit-and-groove erosion
- Incorporation of ion energy with impingement current density to determine erosion rates
- Incorporation of unstructured mesh solver
- Continue to validate model by comparing model results with NSTAR LDT and ELT results